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Editorial: Macroalgal blooms in a global change context

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Editorial on the Research Topic
Macroalgal blooms in a global change context

Following the Second World War, the development of industrial agriculture and medical advances allowed for an exponential increase in the human population. During this period, the concept of mass consumption society was also encouraged in developed and developing countries, increasing the demand for resources (Cherubini et al., 2018; Gaulin and Le Billon, 2020; Elmqvist et al., 2021). The associated expansion and intensification of human activities necessary to cover the needs of a larger and more demanding population led to important changes in the earth system, making humankind one of the most important drivers of global change (e.g., ocean acidification, climate change, eutrophication, biological invasions). All of these human-induced changes in environmental conditions have produced important alterations and imbalances in the structure and functioning of ecosystems, especially in aquatic systems (Lotze et al., 2006; James et al., 2023).

In coastal and estuarine waters, one of the most evident signs of the impact of human activities is the development of macroalgal blooms. Macroalgal blooms are accumulations of fast-growing opportunistic species, which can lead to anoxic events and release nuisance or toxic compounds during the degradation of the biomass (Fletcher, 1996; Valiela et al., 1997; Green-Gavrielidis et al., 2018). These blooms alter ecosystem functioning of nearshore environments and limit the services these areas provide (Fletcher, 1996; Gonzales et al., 2013). Macroalgal blooms became more frequent and larger in the 1970s, especially in industrialized countries. Since then, the number of reports from new locations and the magnitude of these blooms have continued to increase (Smetacek and Zingone, 2013). Important research efforts have been developed in order to understand the causes and mechanisms underlying these phenomena, which have demonstrated the key role nutrient over-enrichment and reduced herbivory play in explaining the occurrence of macroalgal blooms (Pedersen and Borum, 1996; Teichberg et al., 2012; Bermejo et al., 2022). Despite the critical role of nutrient over-enrichment in the occurrence of seaweed tides, additional abiotic and biotic factors such as light (Vergara et al., 1997), temperature (Gao et al., 2017), CO_2 (Xu et al., 2017), local hydrodynamic conditions (Salomonsen et al., 1999), grazing (Nelson et al., 2008), precipitation changes (Green-Gavrielidis and

Thornber, 2022), propagule bank size (Lotze et al., 2000), and local species pool (Bermejo et al., 2023) can be critical in explaining bloom development.

A quick search in Scopus using the term "seaweed tide" that only considered original research, written in English, in the marine environment published until 2022 identified 265 original research articles that were mostly conducted in developed regions (Figure 1A). Species of more than 30 macroalgal genera were reported as responsible for the occurrence of macroalgal blooms. Macroalgal blooms dominated by green seaweeds (especially *Ulva*; Figure 1B; Table 1) were the most studied, although in the last year there has been an increasing interest in golden tides, mostly related to the occurrence of *Sargassum* blooms (Figure 1C). Although these

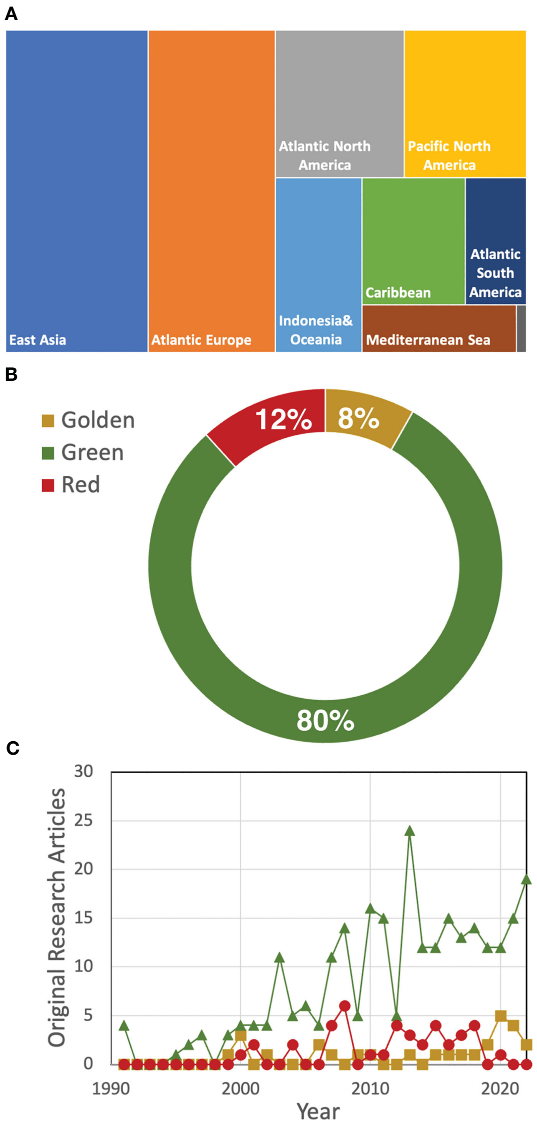

FIGURE 1
Number of mentions in eligible original research articles found in SCOPUS sorted by geographical region -the area is proportional to the number of mentions- **(A)**, type of macroalgal bloom **(B)**, and by type of bloom (green-triangles; golden-circles; red -squares) and year **(C)**. In total, 265 original research articles published until 2022 were considered in the analysis.

TABLE 1 Genera of bloom forming macroalgae recorded in the 265 original articles considered.

Genus	Articles	Phylum
Acanthophora	1	R
Acrosiphonia	1	C
Agardhiela	1	R
Alsidium	1	R
Anadyomene	2	C
Asteronema	1	O
Boodlea	1	C
Botryocladia	1	R
Caulerpa	5	C
Ceramium	3	R
Chaetomorpha	14	C
Cladophora	18	C
Codium	5	C
Dictyota	3	O
Ectocarpus	1	O
Euchema	1	R
Gracilaria	21	R
Gracilariopsis	2	R
Hypnea	4	R
Liagora	2	R
Lobophora	3	O
Microdictyon	1	C
Percusaria	1	C
Pilayella	6	O
Polysiphonia	2	R
Rhizoclonium	4	C
Sargassum	14	O
Spyridia	2	R
Ulva	215	C
Ulvaria	5	C
Willeella	1	C

Please note that one article can record more than one genus. C, Chlorophyta; O, Ochrophyta; R, Rhodophyta.

figures can be biased by differential research efforts in different regions or the use of other terms to define macroalgal blooms (e.g., "bioinvasion"), all these figures give an idea of the complexity and global nature of macroalgal blooms.

Regarding this Research Topic, the scientific contributions published cover a wide geographical range with contributions from Asia, Europe, North America, and South America. Two contributions focused on green tides [*Ulva lactuca* (Reidenbach et al.) and *U. prolifera* (Cai et al.)], two on golden tides [*Sargassum* *horneri* (Xu et al.) and *Rugulopteryx okamurae* (Roca et al.)] and one on a red seaweed bloom [*Trichogloeopsis pedicelata* (Gavio et al.)]. The factors explaining the development of the studied macroalgal blooms are diverse and include the occurrence of extreme climatic events [*T. pedicelata* (Gavio et al.)], biological invasions [*R. okamurae* (Roca et al.)], eutrophication (*Ulva* spp. and *S. horneri*) and changes in oceanic currents (*S. horneri*). Three articles are laboratory-based ecophysiological experiments, two of them (*Ulva* spp.) aimed to understand the effects of acidification in two contexts of nutrient enrichment (high and normal) (Reidenbach et al.; Cai et al.), and one investigated the effects of ultraviolet radiation on *S. horneri* (Xu et al.). The two laboratory-based studies focused on *Ulva* spp. provide useful information for the forecast and management of green tides in a global change context (i.e., ocean acidification), under different scenarios of nutrient management (Reidenbach et al.; Cai et al.). The contribution assessing the effect of an enhanced light condition (including ultraviolet radiation) as a consequence of a change in the habitat of *S. horneri* (i.e., anchored *vs* floating) contributes to a better understanding of the factors explaining the development of golden tides in East China and Yellow Seas (Xu et al.). The other two contributions were field-based studies. The study from the southwestern Caribbean Sea describes the occurrence of a red macroalgal bloom dominated by the rhodophyte *T. pedicellata* following a hurricane (Gavio et al.). To assess and describe the effects of climatic extremes (e.g., hurricanes, heat waves) on marine ecosystem becomes specifically relevant as an increase in the occurrence of these events is expected. The other field-based study developed a methodology for monitoring a non-native species causing extensive macroalgal blooms in southern Spain using Unmanned Aerial Vehicles (UAV) (Roca et al.). Using Earth observation technologies (e.g., UAV and satellites) combined with field surveys will be key for reducing the costs of the necessary environmental monitoring required, while increasing coverage, data reliability and effectiveness (Karki et al., 2021). The wide geographical range covered by the presented contributions and their diversity in taxa, environmental situations, and methodologies reflects the interest and the global concerns around macroalgal blooms in the current context of global change.

Author contributions

Conceptualization: RB, GG, LG-G Data curation: GG, RB. Methodology: RB. Writing and original draft: RB. Writing and review & editing: LG-G, GG. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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